10.4 A 60GHz Transmitter with Integrated Antenna in 0.18µm SiGe BiCMOS Technology

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A 60GHz SiGe HBT transmitter IC with integrated antenna in a standard-bulk 0.18µm SiGe BiCMOS technology is reported in this paper. This chip is composed of a VCO, a sub-harmonic (SH) mixer, a PA, and a tapered-slot antenna, all with differential designs. The measured results show 15.8dBm output power and 20.2dB conversion gain at 281mW dc power consumption.

The unlicensed band around 60GHz provides the possibility of high-data-rate wireless communications while reducing the energy dissipation per bit. In the past, mm-wave ICs have mostly been implemented using GaAs or InP technologies. The silicon-based IC technologies have the major advantage of higher levels of integration. Recently, mm-wave ICs using SiGe HBT and CMOS technologies have been demonstrated [1, 2, 3, 4]. At high frequencies, the short wavelength allows the integration of the antenna on chip with a simple interconnection between the PA and antenna. For example, an on-chip antenna is realized using zigzag dipole for a 20GHz CMOS down-converter [5].

In this paper, a 60GHz SiGe HBT transmitter with integrated antenna in a standard-bulk 0.18µm 1P 6M SiGe BiCMOS technology (substrate conductivity ~10Ωcm) is reported. In this process, the HBT has an f_{max} of 120GHz and an f_T of 130GHz using a 1.5V supply and MIM capacitors (1fF/mm^2) are developed using oxide inter-metal dielectric.

The block and schematic diagrams of this MMIC transmitter are shown in Figs. 10.4.1 and 10.4.2, respectively. For the antenna design, the reduction of the substrate loss is a major challenge to integrate the antenna on the silicon chip. The tapered slot antenna [6], which is a balanced traveling wave antenna, is therefore used in our design. Because of the differential traveling wave structure, most of the electromagnetic fields are confined and propagate along the surface instead of entering the substrate. Also, the substrate mode effect can be reduced. In principal, the overall size should be chosen a little more than one wavelength (λ) long at its low operating frequency range. However, considering the chip size, the strip length is designed for slightly longer than λ/4 at 60GHz and thus the antenna gain and directivity is degraded. This can be compensated for by placing an off-chip director at λ/2 (at 60GHz) away from the end of the tapered slot antenna. The differential PA is implemented by using two identical single-ended amplifiers with the same ground plane. The single-ended PA is a three-stage class-A amplifier and is used to feed the differential antenna directly. A doubly balanced active HBT SH mixer with a built-in cross-coupled VCO as the LO is used to up-convert the IF signal to 60GHz. To make sure that the VCO provides enough power (0dBm) to pump the SH mixer, two buffer stages are added at the output of the VCO. The complete transmitter (without integrated antenna) has a simulated conversion gain of about 23.5dB under an LO drive of 0dBm.

The VCO output is measured via an extra test pad using on-wafer probing. The supply voltage is fed through the virtual ground point (1.6V). The VCO starts to oscillate at a bias current of 3.6mA and V_B of 0.9V. Figure 10.4.3 shows the measured output frequency versus the control voltage of the VCO. With the coarse tuning (V_B), the frequency tuning range at fundamental port is from 28.4 to 30.5GHz. The VCO output power is -8.5dBm at 30GHz with a measured phase noise of -80.2dBc/Hz at 1MHz offset and the power at the output of the buffer stage is about 2dBm. A PA test circuit is also fabricated to evaluate the output power performance. An output matching network fabricated using Duroid 5880 substrate in a 50Ω measurement system is added at the end of the PA test circuit. Figure 10.4.4 shows the on-wafer measured S-parameters at 1.8V voltage supply with 125mA dc current. It presents 12dB small-signal gain from 50 to 60GHz with return losses better than 10dB from 56 to 62.5GHz. At 60GHz, the single-ended PA delivers 12.8dBm saturated output power with 11.5dB of gain. Thus, the complete PA saturated output power should be higher than 15.8dBm if the loss of the extra output matching network is accounted for. The P_{1dB} and IIP3 are better than 11.2dBm and 4.5dBm of the complete PA, respectively.

The receiver setup consists of a standard horn antenna with 24dB gain and a spectrum analyzer along with harmonic mixer. The upper sideband received power of the antenna is measured at the receiver that is 1m away from the transmitter. With the path loss approximated by the Friis transmission formula, the single-sideband isotropic conversion gain is estimated to be 20.2dB. The radiation pattern of the transmitter is measured at 10MHz IF signal. The normalized RF radiation patterns with and without the director are shown in Figs. 10.4.5 and 10.4.6. It is observed that both the E and H plane patterns are symmetrical with higher directivity when adding a director in front of the antenna. Figure 10.4.7 shows the chip micrograph with a die size of 1.3×0.8mm^2.

The LO source provided by the on-chip VCO is included to have a self-contained integrated antenna mixer. An output power of more than 15.8dBm at 60GHz is obtained for the complete PA. A single-sideband isotropic conversion gain of 20.2dB is achieved.

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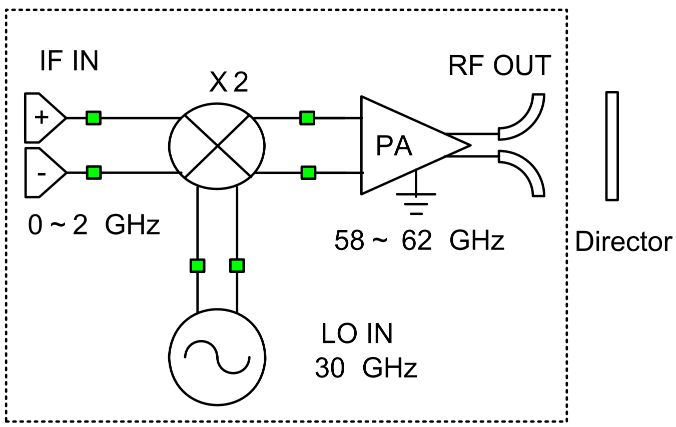

Figure 10.4.1: Block diagram of the 60GHz SiGe transmitter.

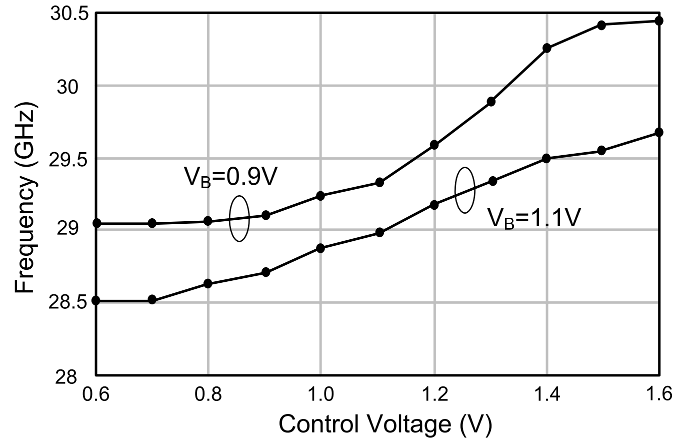

Figure 10.4.3: Output frequency versus control voltage from 0.6 to 1.6V.

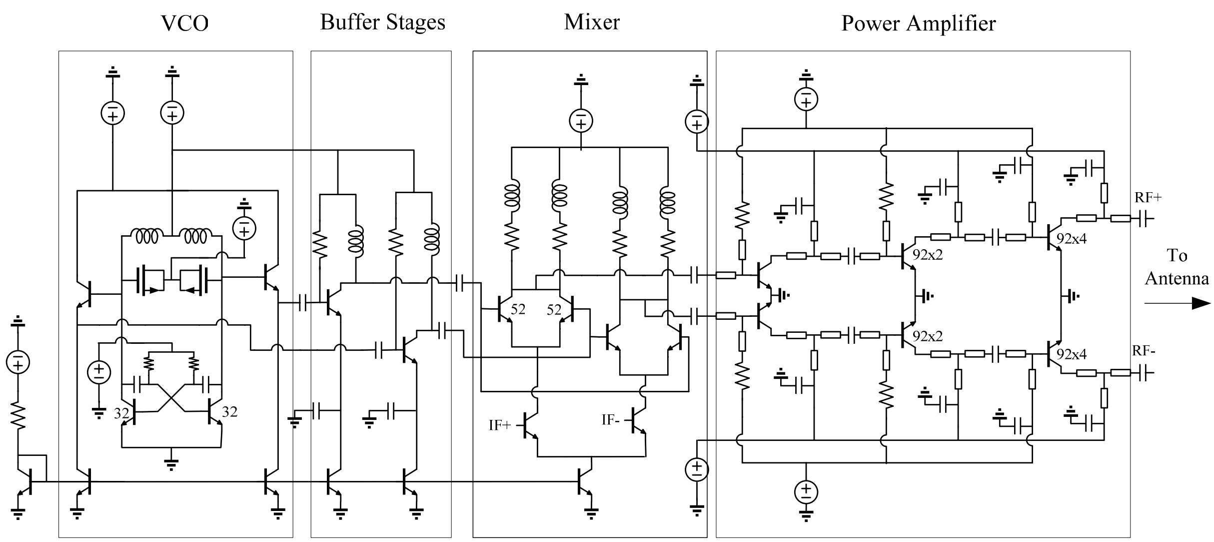

Figure 10.4.2: Schematic diagram of the 60GHz SiGeHBT transmitter.

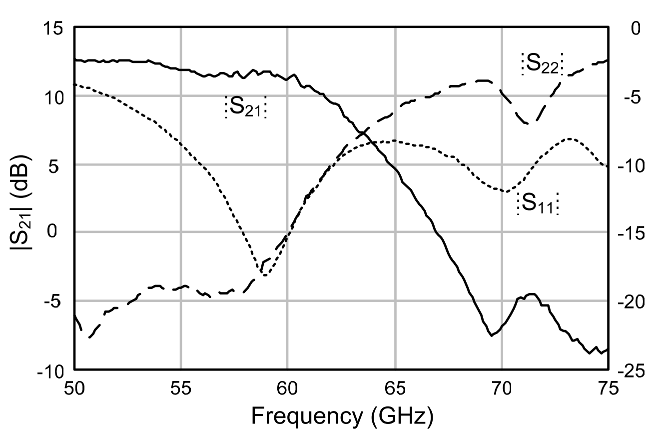

Figure 10.4.4: Measured S-parameters of the single-ended PA test circuit.

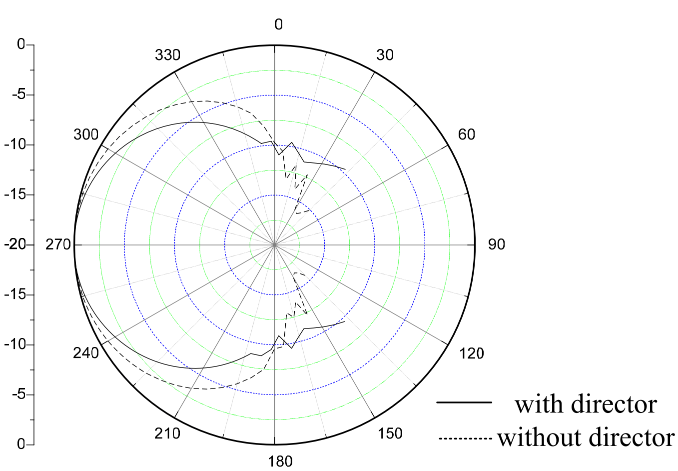

Figure 10.4.5: Measured normalized power patterns with and without director under co-polar receiving condition (E-plane).

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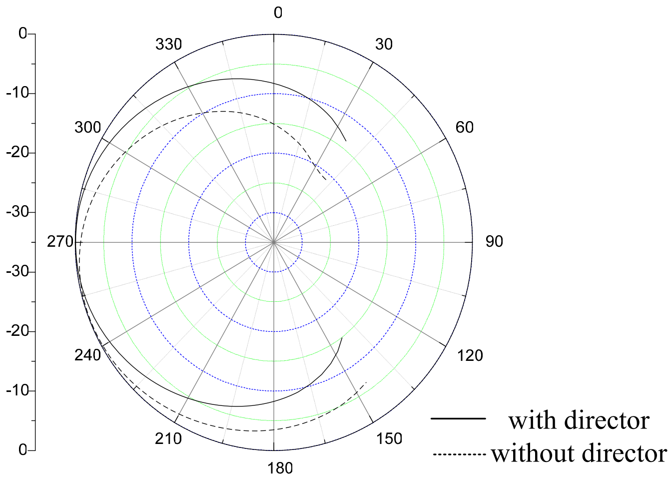

Figure 10.4.6: Measured normalized power patterns with and without director under co-polar receiving condition (H-plane).

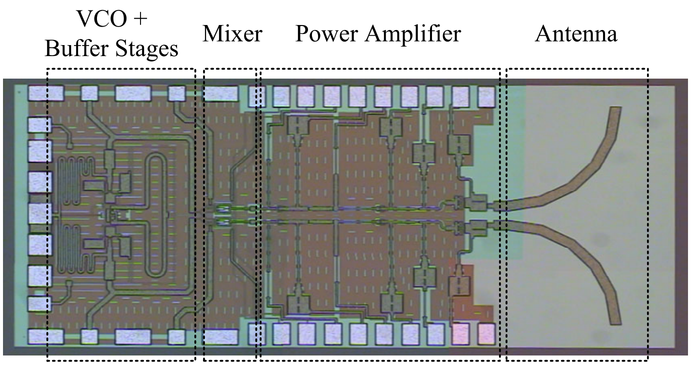

Figure 10.4.7: Chip micrograph of the 60GHz SiGetransmitter. (Size: $1.3\times0.8mm^2$).